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Compact Photonic Transmitter Based on Annular Ring Antenna for THz Applications

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Abstract

This paper presents the design of Continuous Wave Terahetz photonic transmitters based on photodector which convert the light signal to electrical signal, THz antenna, low-pass filter (LPF) and DC Probe. In the design of the CW THz photonic transmitter System, we begin with the matching input impedance and validation of THz antenna using an EM solver Momentum integrated in ADS "Advanced Design System". Then we pass to the optimization of a low-pass filter which had the role of inductance, blocking the RF signal providing from the antenna to reach the DC probe. Finally, we associate the previous structures with a DC probe and simulate the whole circuit until validating the CW THz photonic transmitter circuit. The three structures are based on multi-layers GaAs substrate, which is the most widely used for THz circuit design. The dimensions of the whole circuit are $819.071 \times 164.10\ \mu m^2$.

Keywords*: GaAssubstarte, CW THz photonic transmitter, photodetector, antenna THz, low-pass filter*

1. Introduction

Recently, weremark the fastgrowinginterestgiving to the THzdomain. A diversity of domainssuch as biomedicalimaging, spectroscopy, Security and telecommunications are focusingnowtheirs applications on THzwaveswhichpresentseveraladvantagesbased on interactivitywith the materialwhereitspreads and fast absorption by the atmosphere [1]. Also the apparition of the modern Femtosecond Lasers and High-Speed Photodetectorsgive the opportunity to develop more research in the generation, detection and guiding of THzwaves in the aim to obtain a compact high-power and high-efficiencyTHztransmitter.To generate the THzwavesmanymethods are proposed but the mostusedis the one thatrelays on the coplanarwaveguide (CPW) photonictransmitters [2].

The CPW technologyoffers in factseveraladvantages due to itsfeatures, likelow radiation, low dispersion, easy of shunts and series connections [3].This paperpresents a new design of a CW THz photonic transmitter composed from a photo detector associated to THz antenna inserts in serieswith a lowpassfilter and a DC Probe. Weevoke the theory of different components of the system, then the design and validation of the proposed THz transmitter by using Momentum electromagnetic solver.

2. Photonic Transmitter System

2.1. THz Technology

As mentioned before THz technology attracts more and more searchers. As result it's widen their areas of application and give birth to others. The THz frequency is between microwave and visible waves as illustrated in the Figure 1 and occupies the 100GHz-10THz spectrum. The THz band has various advantages of the application summarized as follows [4]:

a. Microwave band is almost all preoccupied by different services, and its bandwidth is limited. In place of this, the terahertz can offer a wider bandwidth.
b. The diffraction of the THz wave is low in comparison with that of the microwave and millimeter wave, which is the advantageous in the line-of-sight (LOS) and point-to-point link.
c. This band offers high degree of information security, especially in the spread spectrum technology.

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d. In comparison with infrared, THz has low attenuation of the signal in certain atmospheric conditions like fog.

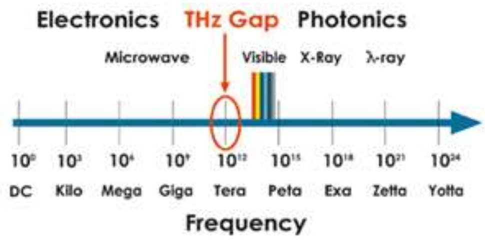


Figure 1. Position of THz band between the microwave and infrared regime of electromagnetic spectrum

2.2. Photodetector “PD”

A PD is a sensor its role is to convert an optical power into an electrical current. To generate electron-hole-pairs, the photon energy provides from the light absorbed in a PD must be at last equal to the bandgap energy Eg of the absorber material [5].This available energy of one photon is sufficient to excite an electron from the valence band (v.b.) to the conduction band (c.b.). For this band-to-band transition, the upper wavelength limit for photon absorption is given by [5]:

$$\lambda_g\,[\mu m] = \frac{1.24}{E_g\,[eV]} \tag{1}$$

A PD has different proprieties such as:
Sensitivity: The ability of the photodiode to transform light absorbed into an electrical current in other term the number of charge carrier pairs generated per incident photon [5].

$$\eta_{ext} = \frac{I_{Pd}}{q}.\frac{h\nu}{P_{opt}} \tag{2}$$

Responsivity: where Ipd is the photogenerated current by the absorption of the optical input power Popt at a frequency v mentied in equation (2). A common figure of merit is the external responsivity R, defined as the ratio of photocurrent to the input optical power [5]:

$$R = \frac{I_{Pd}}{P_{opt}} = \frac{\eta_{ext}\lambda[\mu m]}{1.24}\ A/W \tag{3}$$

In this study we choose the Metal Semiconductor-Metal Traveling wave Photodetector (MSM-TPD) due to its high power-bandwidth and coplanar-waveguide fed slot owing to its easy connection with planar devices [6]. The PD based on GaAs substrate which characterized by a succession of layers as mentioned in the Figure 2 [7]:

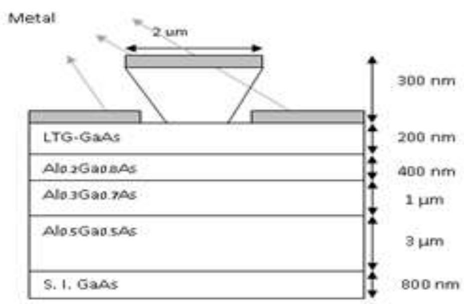


Figure 2. Structure of the photodetector based on GaAs substrate

2.3. THz Antenna

The role of the antenna [8-10] is to transmit the RF signal providing from PD. It presents one of the most important element in the design of CPW THz photonic transmitter. The proposed antenna illustrated in Figure 3 presents an annular ring shape [11-13]. Table 1 shows values of design parameters (Unit in μm).

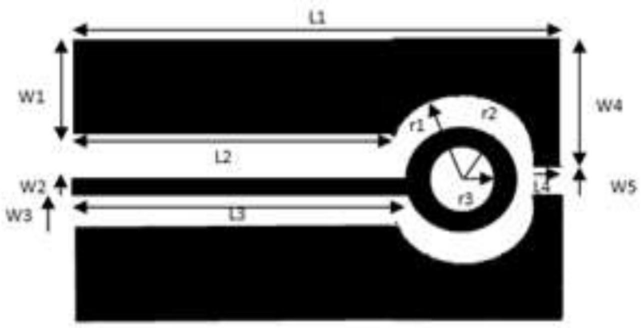


Figure 3. The THz annular ring proposed antenna

Table 1. Values of Design Parameters (Unit in μm)

Dimensions (μm)	Values
L1	176.60
L2	121.42
L3	126.61
L4	5
r1	25.97
r2	21.64
r3	36.34
W1	19.39
W2	5.6
W3	11.06
W4	28.41
W5	6.01

The result of S11 presenting in Figure 4 makes the proposed antenna suitable for THz CW photonic transmitters. The reflection coefficient is below -10dB between the frequency 1.98 THz and 2.02 THz. To obtain the radiation diagram which describes the behavior of the antenna we have launched a 3D simulation at 2 THz in ADS as shown in Figure 5. As presented the radiation patter is multidirectional with stable radiation.

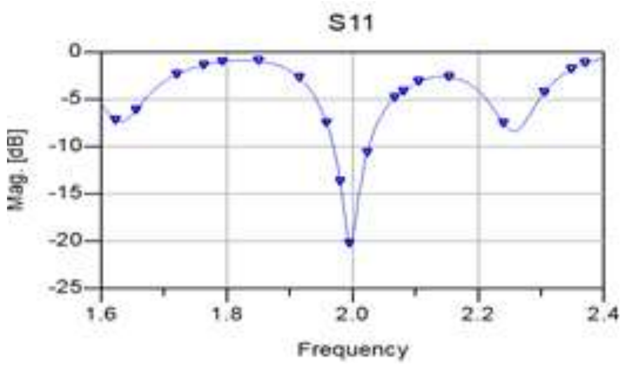


Figure 4. Reflection coefficient versus frequency

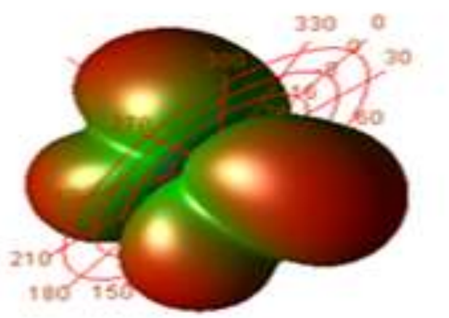


Figure 5. The radiation pattern at 2 THz

2.4. Low-Pass Filter “LPF”

To block the RF signal providing from PD and transmitting via antenna, to reach the DC probe the integration of Low Pass Filter into the CW photonic transmitter system permits to block the RF signal from reaching the DC probe. Figure 6 presents a several periodic structure composed from three units inspired from the study [14-15]. The Table2 resumes the different dimensions of the proposed LPF:

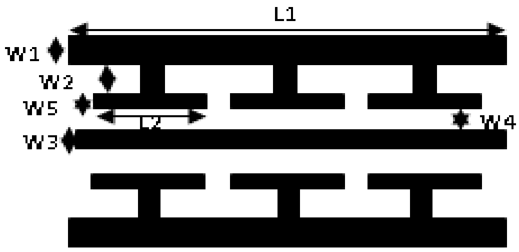


Figure 6. The layout of the periodic LPF THz structure

Table 2. Filter Dimensions (Unit in μm)

Dimensions (μm)	Values
L1	300
L2	60
W1	20
W2	10
W3	17
W4=Gap	5
W5	5

As presented in Figure 7 the LPF presents a low insertion loss, with a cutoff frequency of 0.45 THz and a wide rejection band until 1.2 THz, The phase of S21 coefficient is presented in Figure 8.To study the behavior of the LPF structure, we have launched a simulation at 0.3 THz in the frequency passband. In addition, at 1 THz in the rejection band. As shown in Figure 10 the conclusion is the filter « LPF » playsitsrole, at0.3 THzunder the cutofffrequency the RF energypassfrom port 1 to port 2 and at 1.15 THz the energyhadstoppedwhichimprovesthat the proposed LPF issuitable for THz system.Figure9 shows the current density @ (a) 0.3 THz and 1 THz.

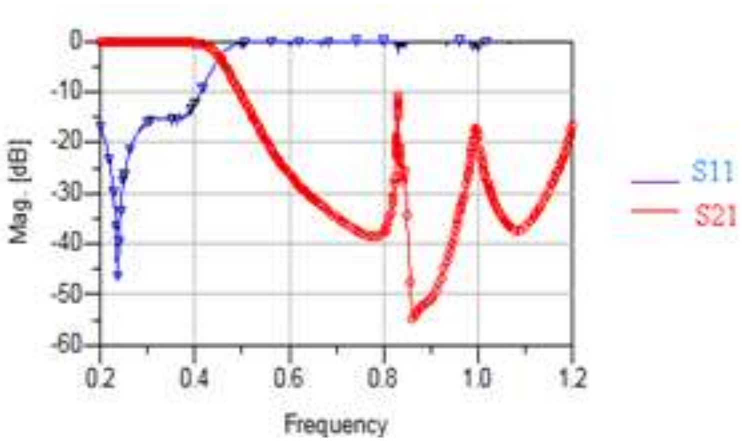


Figure 7. Simulation S-Parameters results versus frequency

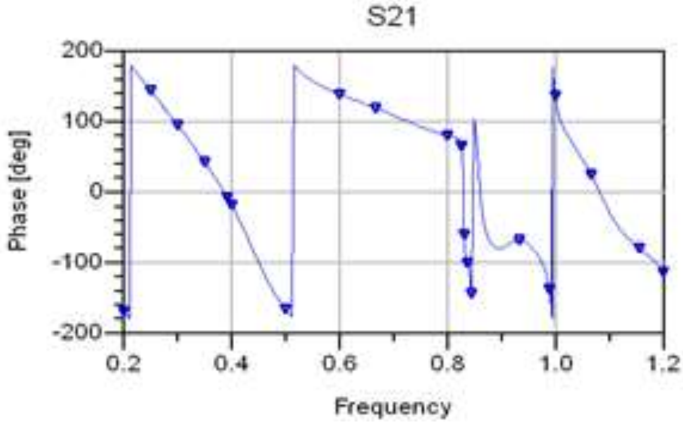
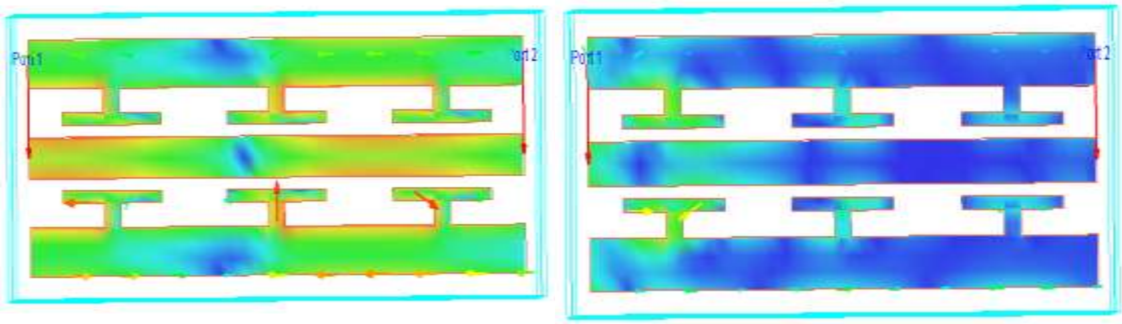


Figure 8. Phase of S21 versus frequency



(a) (b)

Figure 9.The current density @ (a) 0.3 THz and 1 THz

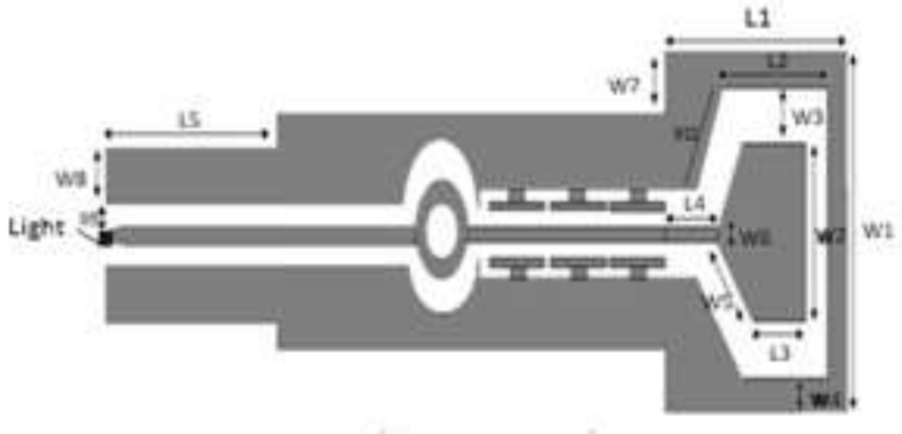


Figure 10. The proposed CW photonic transmitter

2.5. CW Photonic Transmitter Simulation

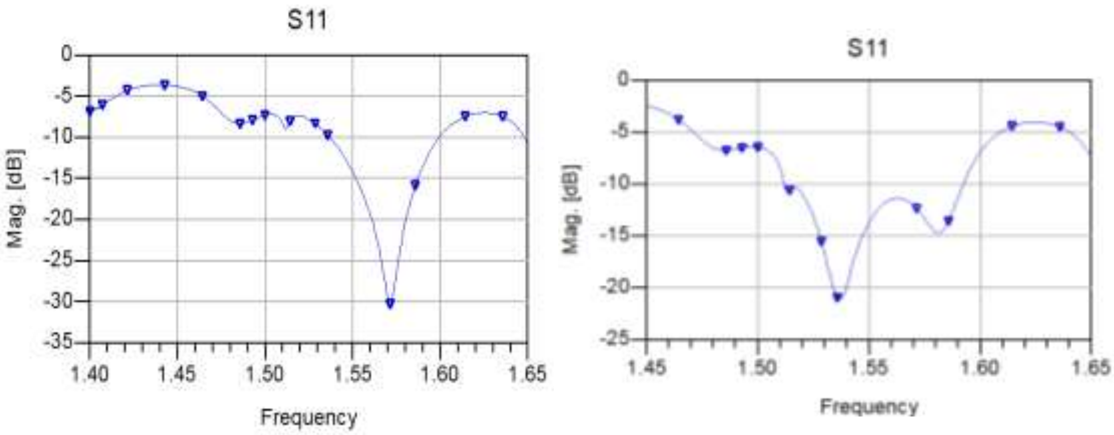
After presenting the annular ring THz antenna and the “LPF”, we have associated the photodetector to the system composed from the antenna, the filter and DC probe responsible for the DC bias to obtain the CW photonic transmitter system.Table 3 showsvalues of DC probe parameters.

The proposed photonic transmitter was firstly optimized for an input impedance equal to 50 ohm, the circuit presents a good matching input impedance as shown in Figure 11(a) with a narrow bandwidth. To take into account the input impedance of the photodetector around 30 Ohm we have simulated the THz transmitter which permits to obtain a large matching input impedance between 1.51THz and 1.59THz.

Table 3. Values of DC Probe Parameters

Dimensions (µm)	Values
L1	238.11
L2	114.95
L3	98.52
L4	83.13
L5	107.76
W1	163.18
W2	104.68
W3	17
W4	10.26
W5	71.88
W6	12.31
W7	33
W8	15.42
W9	6.67
W10	61.58

After the validation of this THz photonic transmitter into simulation we have done a comparison between the proposed THz antenna which is the key of the THz source and another THz antenna validated in literature. The Table 4 presents the comparison of the performances (dimensions, frequency bandwidth) between the proposed antenna and two others structures: As shown in this table, the proposed antenna presents good performances in term of bandwidth and length.



(a) (b)

Figure11. Simulation S-Parameters results versus frequency (a) input impedance 50 Ω(b) For 30 Ω input impedance

Table 4. Comparison of the Antenna Structures

Antenna Structure	Length	Frequency Bandwidth
Proposed Antenna	172.24µm	[1.98 Thz,2.02 THz]
Antenna[17]	330 µm	[1THz,1.25THz]
Antenna [18]	200 µm	Narrow band at645 Ghz
Antenna [19]	1040 µm	Narrow bandat 850 Ghz

3. Conclusion

The aim of this paper is the validation of CW photonic transmitter using for generation of THz waves. As mentioned the CW photonic transmitter composed from Photodetector, Antenna, LPF and DC probe. Thus our study begin with the choice of Photodetector MSM-TPD which converts the light signal to electrical one, the optimization of the THz Antenna then the validation of low pass filter and finally we have associated all structures in series, the whole circuit was optimized and simulated using an electromagnetic solver Momentum integrated in ADS until reaching the desired results. The final circuit is mounted on a multilayer GaAs substrate and having an area around $819.071 \times 164.10\ \mu m^2$.

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